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Measures Of Effectiveness In Systems Analysis And Human Factors

by

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FOREWORD

This report may be of most value to the relatively inexperienced human factors engineer who must support the analysis activities associated with a systems design effort. The human factors engineer can contribute a lot to such an effort, and ensure that sufficient attention is paid to the operator performance part of the analysis. With practice, the human factors engineer can do most of the analysis, providing useful results to the rest of the design team; the results can also be used to support human operator requirements with hard numbers.

Systems engineers may also gain an understanding from this report of how operator performance considerations can be included in systems analysis and design.

The work for this report was performed at the Naval Weapons Center (NWC), China Lake, Calif. This report was written to expand on a section of NWC TP 6541, *The Human Operator and System Effectiveness*, as part of an effort by the U. S. Navy's Human Factors Block program on analysis development in Human Factors. The report supercedes the NWC TM 5332, *Measures of Effectiveness in Systems Analysis (Including Human Factors)*. The work was supported by the Human Factors Block under the direction of the Naval Air Development Center (NADC), Warminister, Penn. The work was conducted between January and July 1984 under AIRTASK A330A330J/1001B/4WF57525000 and in June 1986 under NADC Work Request No. N62269/86/WR/00042, NPRD Document No. N68221/86/WR/60028.

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(U) This report presents information from a number of sources on the development of measures of effectiveness (MOEs) for use in human factors and systems analysis. MOEs are structured in a hierarchy, going from the top-level MOE that indicates the worth of a system, through MOEs of mission capability, down to MOEs or measures of the performance of individual tasks making up a mission. Human operator performance is usually found explicitly at the lower levels in the MOE hierarchy.

(U) Guidelines are presented for developing the MOEs for a system's capability to accomplish a mission. Desirable characteristics of MOEs are also provided; implication for relating human operator performance to overall system capability or system worth are discussed.

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EXECUTIVE SUMMARY

This report illustrates that the MOEs associated with any particular system or analysis are hierarchical in nature. The top-level hierarchy includes factors such as cost, survivability, reliability, and capability. The second-level hierarchy includes an expansion of each of these MOEs. The development of capability MOEs is the topic of this report.

The procedures to follow in developing capability MOEs for an effectiveness analysis include separating the mission objectives from one another, identifying the functions that must be performed to complete each objective, and quantifying the performance so that the MOEs can be calculated. This report gives the steps and techniques to follow in developing MOEs. Diagrams showing the procedures to be followed are given at the end of the report (pages 40 through 45).

The performances of system components, or of the human operators of a system, are not found explicitly at all in the top-level hierarchy. This means that there is no "visible" connection between human performance in system operation and the overall "worth" of the system.

In the "capability hierarchy", there is a transition between mission MOEs and individual task performance. It is possible to go down at least two levels in the hierarchy before encountering individual system components or human operators of components. Hence, again, there need not be a "visible" connection between mission capability and individual human operator performance, unless special attention is given to making the connection explicit.

INTRODUCTION

The analysis of the operation of a system or the estimation of the effectiveness of a system, must include the determination of measures of effectiveness (MOE). Equivalent terms found in the literature are measures of merit, figures of merit, and performance criteria.

MOEs are also required for the design of tests and human factors experiments (dependent variables are, or can be related to, MOEs). The choice of relevant MOEs is critical to the validity, credibility, and acceptance of the analysis or test results.

This report presents information from a number of sources on the development of MOEs. Classification schemes are provided to aid in the selection of MOEs for analysis and testing, and guidelines are given for developing MOEs for use in effectiveness analysis.

BACKGROUND

The general procedures to be followed in conducting an effectiveness analysis were outlined in a recent report (Reference 1). One of the major tasks in the analysis procedure is the development of appropriate measures of effectiveness (Box 3, Figure 1). Some guidelines for the development of MOEs are given in Reference 1, but the complexity and criticality of MOEs were not given appropriate attention. This report expands on the MOE section of Reference 1.

NOMENCLATURE AND MOE CLASSIFICATIONS

The development of measures of effectiveness is a broad and complex topic; MOEs are found at most stages of research, system design, development, and evaluation, although they are not always called MOEs.

This report is intended to be a useful guide to the analyst in developing MOEs for use at a particular level of analysis. It is necessary to define the terms and limit (or delineate) the scope of the report to make it as specific and useful as possible. This section of the report will aid in that process.

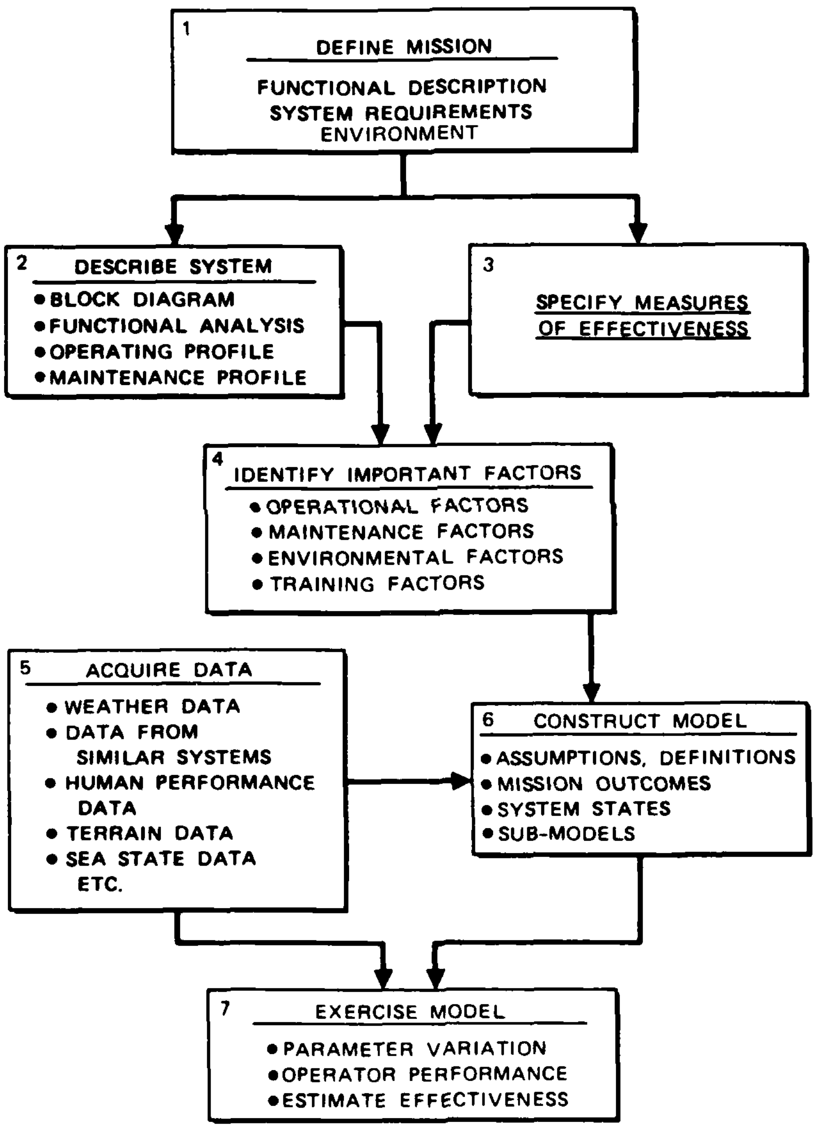


FIGURE 1. Principal Tasks Required for Evaluation of System Effectiveness.

SYSTEM

This study deals with systems which include human operators. A definition that fits the topic of this report (and the analysis procedures presented in Reference 1) is given below.

1. A man-machine system is a set of interfacing components composed of humans and machines (including software) directed toward performing a function or number of functions and operating within the constraints of time and specified environments.

SYSTEMS EFFECTIVENESS

The Air Force defines systems effectiveness as (Reference 2):

1. A measure of the extent to which a system may be expected to achieve a set of specific mission requirements, and which may be expressed as a function of:

   Availability
   Dependability
   Capability

where,

Availabilty is a measure of the condition of the system at the start of the mission at any point in time.

Dependability is a measure of the system condition at one or more points during the mission.

Capability is a measure of the ability of the system to achieve the mission objectives and specifically accounts for the performance spectrum of a system.

MOE DEFINITIONS

Component measures that lead to the quantification of system effectiveness have several names:

Measure of Effectiveness (MOE)
Figure of Merit (FOM)
Measure of Merit (MOM)
Effectiveness Measure
Effectiveness Criterion
Criterion Measure
Criterion

The first term on the above list will be used in this report because it seems to occur more often than the others in the literature.

Reference 3 provides a good definition of measure of effectiveness:

1. An MOE generally is a quantitative expression of the degree to which a system meets its objectives, and hence an analytical standard of comparison. Also, an MOE is a criterion expressing the extent to which a combat system performs a task assigned to that system under a specified set of conditions.

Suffice it to say that there are a number of definitions of MOE, and that they are all dealing with the same or very similar concepts. Further definition of the MOEs in this report can be made by way of classification schemes.

MOE HIERARCHY

Level of the Analysis

There are several levels of analysis, ranging from that conducted to specify component characteristics all the way up to that dealing with the large-scale employment of a number of systems. The hierarchy of useful analyses, in military terms, is indicated in Table 1 - with the hastily added proviso that it is just an example to illustrate the concept. This report addresses level three more than the others.

Figure 2 shows the concept of combining MOEs from each level to get to the next higher level. This report deals only with MOEs for system capability, but it must be noted that these MOEs are combined with others to get to the next higher level. It is important to be aware of the impending combination, so that whatever is generated will be usable later.

Figure 2 is only an example used to illustrate the concept of combining MOEs. Other methods of combining the factors shown may be used in some analyses. For example, the survivability MOE may be an input to a system performance MOE in some cases.

The concept of building up to a system capability MOE is shown in Figure 3. The performance of individual components or human operators is combined in appropriate fashion to obtain the desired MOE. Ways of identifying and combining these performances will be discussed later.

TABLE 1. Example of Analysis Hierarchy.

	Level of analysis	Footnotes	
7.	Force-level employment of many systems	C	
6.	Tactical employment of many systems	A,C	
5.	Multi-element mission performance	A,B	
4.	Mission performance with one system	A,B	X
3.	Mission-segment performance with system	A,B	X
2.	Subsystem performance (with operators)	A	X
1.	System component and operator performance	A	

A - Should include operating procedures and environmental conditions.

B - Should include opposition or adversary, if applicable. This may result in additional or different MOEs.

C - Must include opposition or adversary, if applicable. This may result in additional or different MOEs.

X - Discussed in this report.

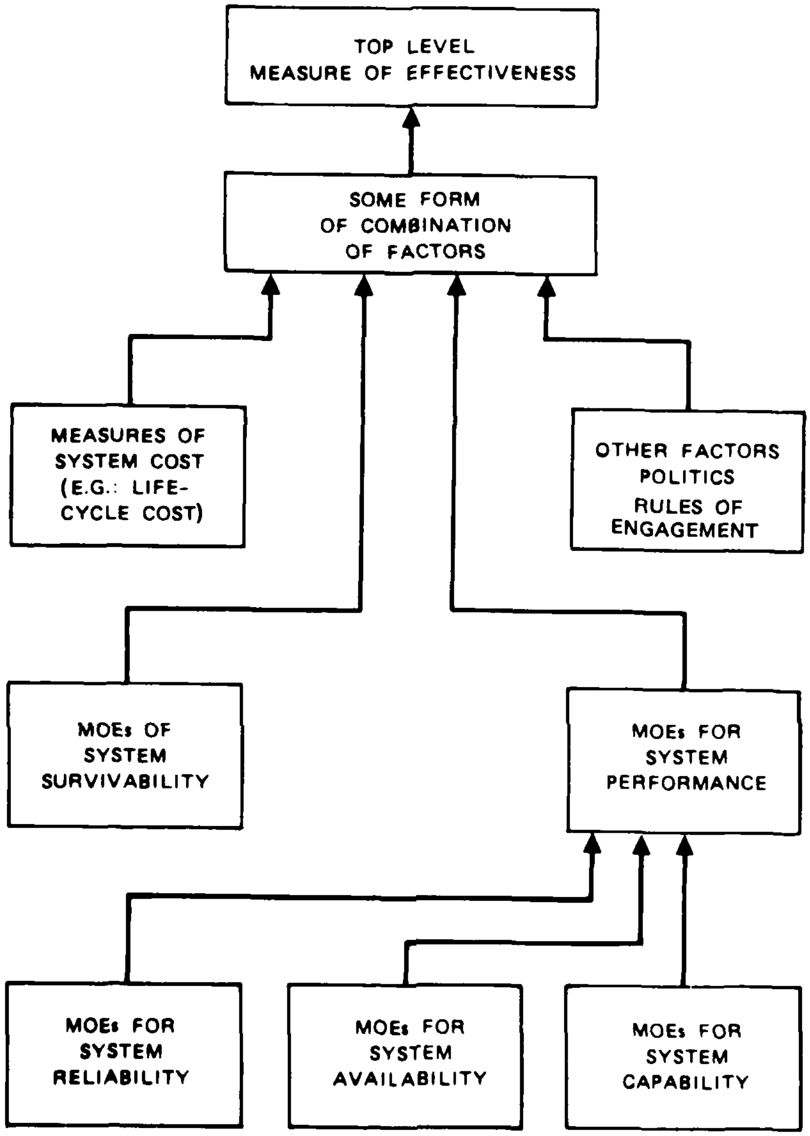


FIGURE 2. Diagram Illustrating the Concept of Combining MOEs.

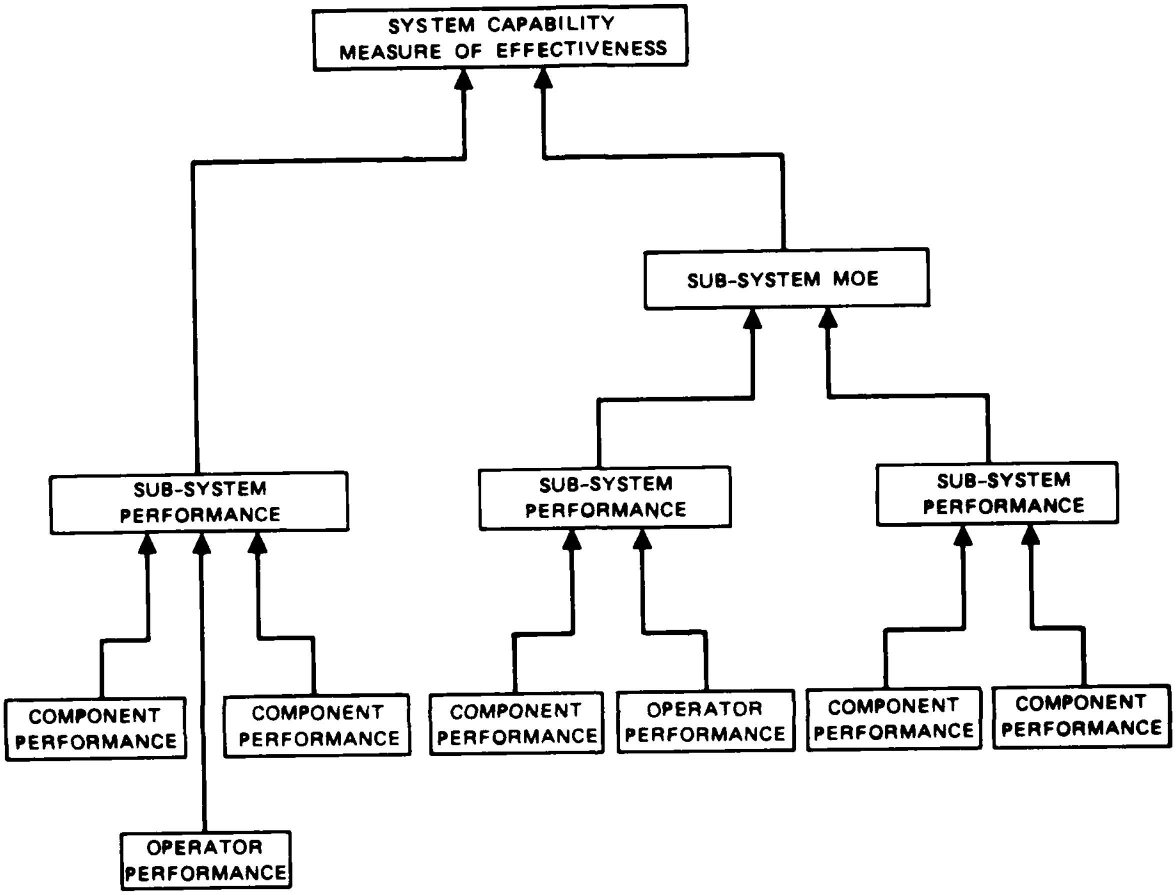


FIGURE 3. Concept of MOEs Developed from Combining Component Performances.

Performance Versus Effectiveness

The terms used in Figure 3 require definitions; for example, is "performance" the same as MOE? When does one merge into the other? Some guidelines to the concepts presented in this report are given in Table 2, but the reader should be aware that other definitions are used and lead to equally valid analysis guidelines and results. However, Table 2 will be useful in interpreting the concepts in this report.

TABLE 2. Guidelines to Word Usage in this Report.

Composite MOE	-	MOE made up by combining other MOEs.
MOE	-	A quantitative expression of the degree to which a system meets a specific objective.
MOE component	-	Any quantity that is used in combination with others to calculate a MOE; a quantity calculated from the performance values (e.g., cursor displacement from target) and other parameters in the problem (e.g., time) to produce a capability measure (e.g., time-on-target).
Performance	-	The output of a component, human operator, subsystem, or system.

NOTE: These definitions are not intended to be mathematically rigorous, mutually exclusive, or the only ones worth using. They are intended to show the hierarchy of MOE formation.

HUMAN FACTORS AND MOEs

Very little has been said thus far about the connection between human factors and MOEs, except in Figure 3. Comments made about human factors testing illustrate that the same concepts and terms used in Table 2 have been in the human factors world for some time (Reference 4):

"Independent variables may be of four different types:

1. Environmental variables
2. Personnel variables
3. Mission variables
4. System variables.

Dependent variables are measures of performance outcomes of the system. They are also sometimes called criterion measures or more simply, criteria. The ideal, or ultimate, criterion is one that measures the performance of a system under completely operational conditions."

Meister has been a strong advocate of a systems approach in human factors, as shown in the edited quote below (Reference 5).

> Personnel subsystem measurement deals with performing the total task or job in the context of the actual system environment. The meaningfulness of individual and team performance data lies in its effect on the higher order structure (the subsystem and system) in which performance occurs.

The hierarchy going from human performance dimensions to operator tasks to system performance measures to system criteria was developed for use in determining future test development in space applications (Reference 6). The relationships between mission requirements, performance measures, and performance criteria were also discussed.

There are other explicit examples of the development of measures of effectiveness in the human factors literature. Winterberg, Bricston, and Wulfeck had to face the problem of developing MOEs for landing aircraft on Navy aircraft carriers (References 7 and 8). Ciavarelli and Williams had to develop MOEs for air combat with a training application (Reference 9). And Ketchel and McGrath developed components of system effectiveness for evaluating the performance of airborne forward air controllers (Reference 10).

MOEs have been included in human factors work for some time, sometimes by another name. This report will attempt to synthesize this and other work to produce general guidelines for developing MOEs. The link between operator performance and the measure of effectiveness will be illustrated.

This section of the report has presented the concepts of a system, system effectiveness, and measures of system effectiveness. The scope of this report is limited to developing measures of effectiveness for use in the analysis process described in Reference 1; that is: <u>the capability of a single system to accomplish its mission during operational employment at the mission segment level</u>.

It is important to note that this report addresses only a small piece of the total picture, as shown in Figure 2. The other factors shown in Figure 2 will be considered in most programs, but their discussion in more detail is outside the scope of this report. Those interested in other MOE development (e.g., for training) may still find some useful information or guidelines in this report.

Additional supplemental information on MOE definitions and desirable characteristics is given in the Appendix. For those with limited background in this aspect of analysis, the appendix could be read now.

MOE DEVELOPMENT

TOP-LEVEL MOEs

If analysis has been conducted properly, the mission has been defined and the system has been described (Figure 1). These activities shall be reiterated in the following text, with a focus on develcping specific capability MOEs.

Separate Missions

Most systems are required to perform more than one assignment or mission. It is necessary to keep these missions separate in analysis and associated discussions, or considerable confusion can result. Figure 4 shows the first cut at breaking the general mission objectives into units that are appropriate for analysis. Figure 5 shows two examples of this process. In the automobile example, only one separation is required, whereas the aircraft example illustrates that sometimes separation should be taken to a second level.

The reader should note that the procedures figures (e.g., Figure 4) given throughout this section of the report are reproduced all together at the end of the report for more convenient reference and use.

The single "concept of employment" can be used as a check to see that there are only one system and one associated mission objective being listed at a time.

Define General Functions

A further test of whether or not the missions have been separated properly is to compare the functions that must be performed in each mission. The functions therefore must be defined at this point in the analysis.

Figure 6 shows that the system description, mission objective, and concept of employment are all used to derive the general functions that must be performed to complete the mission as conceived. This identification of functions should also be conducted at a top level, without getting too specific. A diagram similar to Figure 7 can be used to illustrate the functions arranged along a time or distance line. Important events can be shown, or the mission timeline could be broken into segments if it is helpful to the analyst.

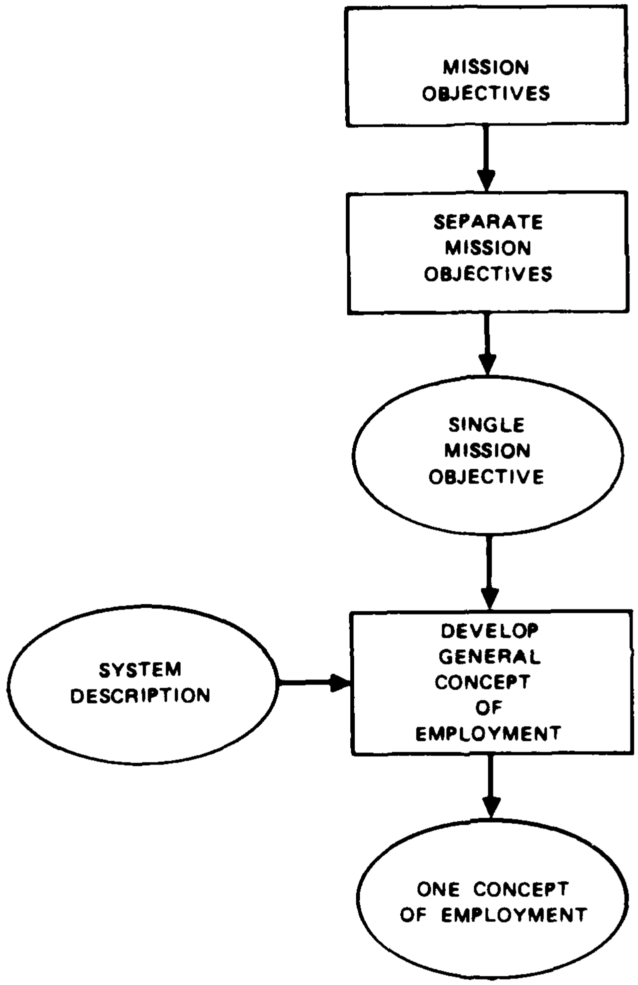


FIGURE 4. Process for Separating Missions.

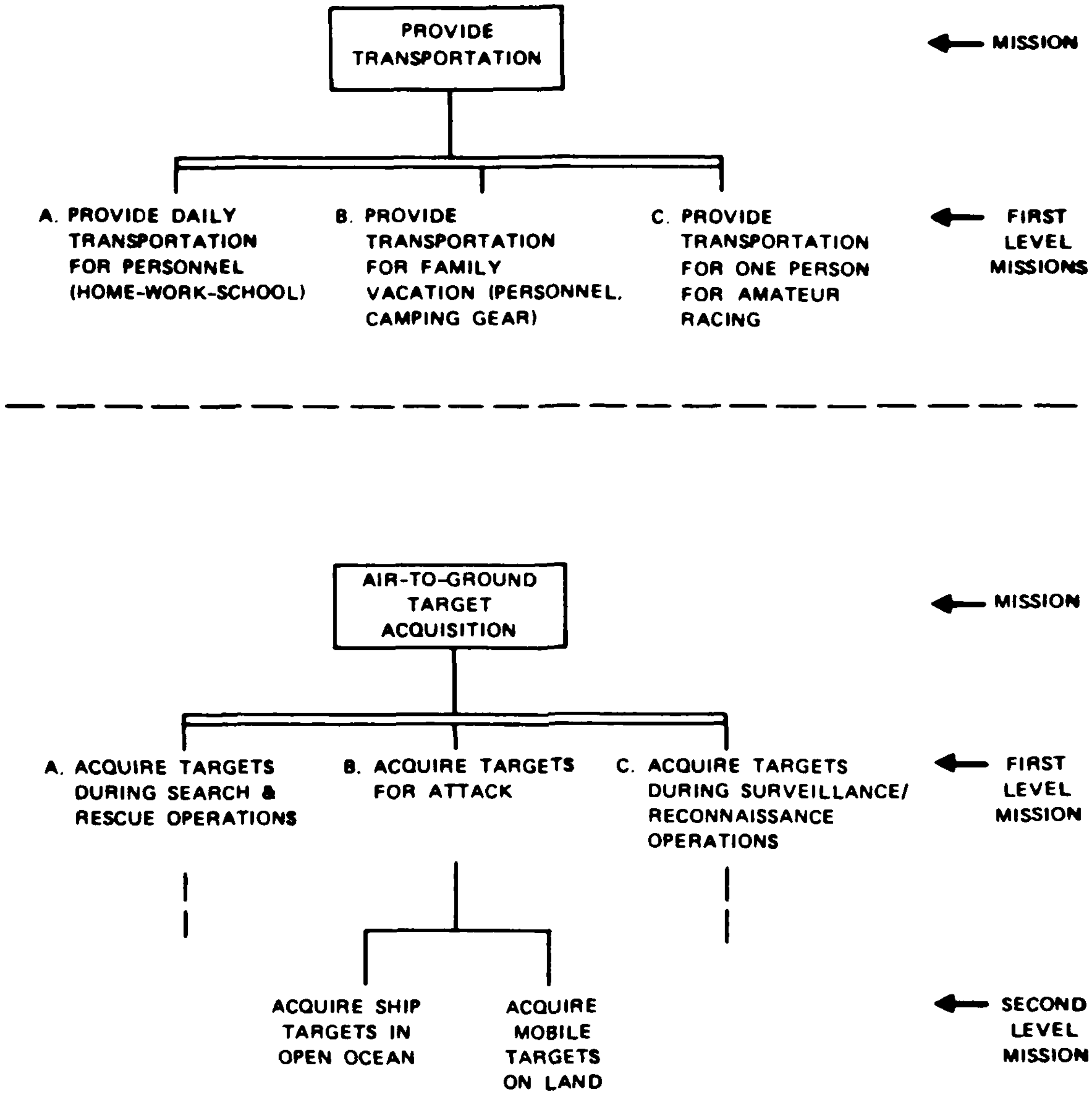


FIGURE 5. Two Examples of Separation of Missions.

Functions should be defined for each of the separate missions. These lists or diagrams of functions can then be compared across the separate missions; if they are different, the missions have been properly separated. If lists of diagrams are the same, the missions from which they were derived might be combined again.

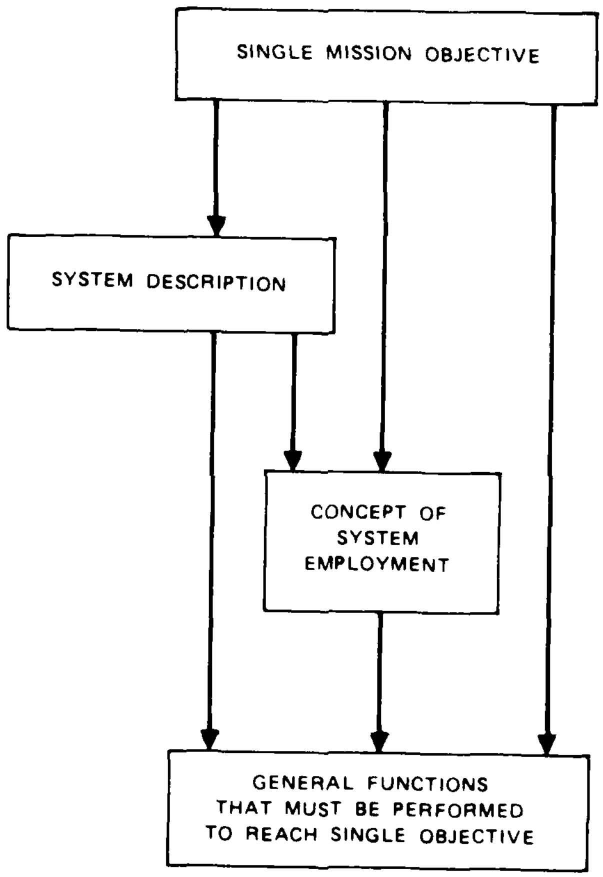
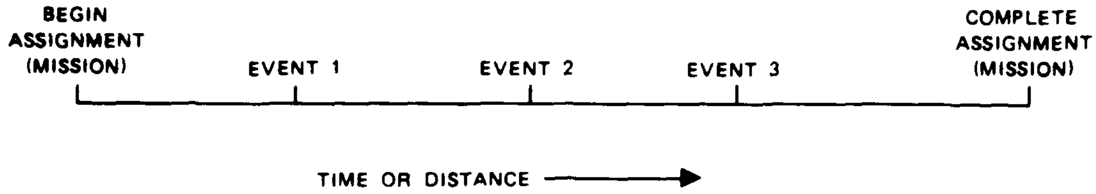
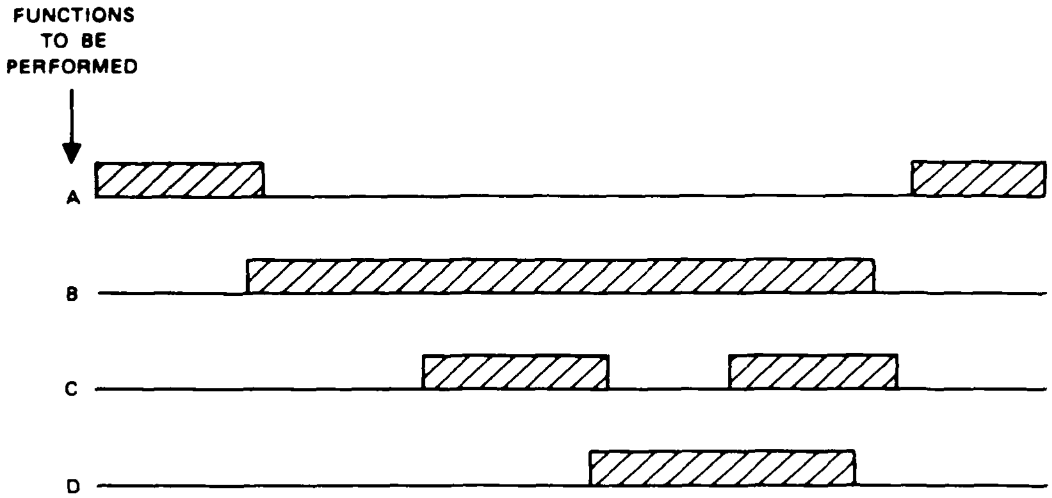


FIGURE 6. Inputs to the Development of General Functions for System Capability.



a. Timeline with Events Shown.



b. Functions Shown Along Timeline.

FIGURE 7. Diagram of Events and General Functions That Must Be Performed During Mission.

Note that a function allocation (a human factors analysis process) has not yet been done. The missions have been separated to the point where their top-level functions differ. Top-level MOEs can now be generated.

Example functions for the two systems shown in Figure 5 are given in Tables 3 and 4. The functions for daily and vacation transportation are very similar in Table 3. The analyst might combine these two "missions" at this point in the analysis. The amateur racing function are clearly different from the others, so racing must be kept as a separate mission.

TABLE 3. General Functions to be Performed with/by a Transportation System. (Assume system is an automobile.)

A. DAILY TRANSPORTATION

1. Unlock automobile
2. Load automobile (people)
3. Start automobile
4. Drive automobile
   Enter traffic
   Follow public roadways (paved)
5. Park automobile
6. Unload automobile
7. Lock automobile

B. FAMILY VACATION TRANSPORTATION

1. Unlock automobile
2. Load automobile (people and camping equipment)
3. Start automobile
4. Drive automobile
   Enter traffic
   Follow public roadways (paved and gravel)
5. Park automobile
6. Unload automobile (people and equipment)
7. Lock automobile
8. Conduct day trips (as in Part A)

C. AMATEUR RACING

1. Load automobile (one person)
2. Drive automobile onto trailer
3. Unload automobile
4. Tie down automobile on trailer
5. Tow automobile to raceway
6. Drive/push automobile off of trailer
7. Fuel/service automobile
8. Load automobile (one person)
9. Start automobile
10. Drive automobile on raceway
11. Drive automobile onto trailer
12. Unload automobile (one person)
13. Tie down automobile on trailer
14. Tow auto home
15. Drive/push automobile off of trailer

TABLE 4. General Functions to be Performed with/by a Target Acquisition System.

A. SEARCH & RESCUE

1. Activate system
2. Test system functions
3. Select target signatures to be detected (e.g., beacon characteristics)
4. Fly specific pattern/route
5. Search
   - Scan
   - Detect objects
   - Sort/identify objects
6. Identify pre-designated "target"
7. Determine/record/mark target location

B. ATTACK

1. Activate system
2. Test system functions
3. Fly to target area as preplanned
4. Search
   - Scan
   - Detect objects in scene
   - Maintain geographic orientation
   - Identify target cues
   - Detect/identify target
5. Track target

C. SURVEILLANCE/RECONNAISSANCE

1. Activate System
2. Test system functions
3. Fly specific pattern/route
4. Search
   - Detect objects
   - Record images
   - Record sensor location and pointing angles
   - Identify potential targets
5. Return to base
6. Play back or view imagery
7. Reduce/interpret images and locations

Each top-level MOE should have three parts:

1. A Statement of Capability
2. A Statement of Operating Conditions
3. General Quantification "Rules" or Concepts

The capability and operating conditions are derived from the mission objective and employment concepts. The quantification concept is required in the generation of the components of the top-level MOE.

Note that this preliminary set of MOEs (or perhaps only one MOE) should be related only to the mission objective, not to the mission functions shown in Figure 7.

Develop Top-Level MOE

Table 5 lists the groups associated with an effectiveness analysis including engineers, managers, and sponsors. A formal effort should be made to get from these people the questions they would like to have answered by the analysis.

TABLE 5. Example of the Participants in the System Effectiveness Analysis Process.

Participants	Example of specialty	Remarks
1. Analysts	Systems Analysis Human Factors	Members of concept, design, and evaluation team.
2. Engineers	Mechanical Electronic Optical Human Factors	Principal members of the design team.
3. Scientists	Atmospheric Physics Computer	Usually consultants.
4. Current users	Pilot Vehicle Driver	May not be near design team, or understand the design process.
5. Managers	Branch Chief Project Head Program Manager	Coordinate and direct work.

TABLE 5. (Contd.)

Participants	Example of specialty	Remarks
6. Principal design team members	Managers Analysts Engineers User representatives	Should be a cohesive group each with designated areas/ responsibilities.
7. Sponsors	Higher Level Manager	Can be regarded as customer, but may not be the actual user.
8. Administration	Budget Procurement	May only be concerned the procurement, schedules, and the budget process.

At this point, then, the analyst has: (1) a single-mission objective, (2) a top-level system description, (3) concepts of employment of the system, and (4) some of the questions that need answering. Table 6 was derived from guidelines given in Reference 11, pages 3-13, and can be used in developing a preliminary set of top-level MOEs. Table 7 is a similar set of instructions for this same process (Reference 12); Tables 6 and 7 are combined in Table 8 to give this report's recommendations in developing a top-level MOE. Table 8 is reproduced at the end of the report together with the procedures diagrams for more convenient access by the user.

TABLE 6. Steps in MOE Development (Reference 11).

Question: What concepts can be used to estimate whether or not a mission objective has been reached?

1. Create as many MOEs as possible; brainstorm, even though at first many of them may appear to be alike.

2. Categorize these MOEs into groups of similar measures.

3. Classify the MOEs as being strong or weak.

4. Eliminate MOEs from the list because of:

    a. Technical infeasibility
    b. Economic infeasibility
    c. Alternatives clearly dominate MOEs

TABLE 7. More Steps in MOE Development (Reference 12).

1.	List the important mission features, so that the MOEs will have a better chance of reflecting the way a mission must be conducted to be effective.
2.	Develop an extensive list of conceivable MOEs for the mission, without initial constraints on this brainstorming.
3.	Reduce this list by discarding duplication and MOEs that are not in some way related to the mission objective.
4.	Write a brief discussion of each of the MOEs and give the analyst's views of some of the general characteristics of each MOE. Include: a. Relation of MOE to mission objective b. Inherent assumptions connected with MOE c. Ways the MOE can be misinterpreted or misleading

TABLE 8. Steps to Follow in Thinking up Candidates for Top-Level MOEs.

1. List the single mission objective as determined in the procedure illustrated in Figure 4.

2. List questions that need answering as obtained from sponsors, program managers, design engineers, etc.

3. Develop a list of many conceivable MOEs for the mission objective, without any initial constraints. Use a brainstorming technique if possible.

4. Write a description of the quantification concepts for each MOE listed.

5. Categorize the MOEs into groups of similar measures.

6. Reduce the list by combining (or discarding) duplicate or redundant MOEs.

7. Further eliminate MOEs from the list because of:

   a. Technical infeasibility
   b. Economic infeasibility
   c. Weak or no relation to mission objective

8. List the remaining top-level MOEs for the single mission objective given in (1) above.

9. Repeat the process for each single mission objective.

Two examples of using Table 8 on missions, taken from Figure 5, are given in Tables 9 and 10.

TABLE 9. Example of Top-Level MOE Process for Family Vacation Transportation. (According to Table 8.)

1. Objective: Provide transportation for single family and camping gear during vacation.

2. Questions: How many people must vehicle transport? How much camping gear must be hauled? (Sample for this example.)

3. List of MOEs

   a. Mileage
   b. Number of passengers possible
   c. Volume of cargo space.
   d. Total volume for passengers and gear
   e. Cargo capacity (weight)
   f. Distance between refueling
   g. Total hauling weight (passengers plus cargo)
   h. Speed up 5% incline with full load
   i. Number adults and number children
   j. Comfort of passengers

4. Quantification of (3) above

   a. Miles per gallon
   b. Number of seats
   c. Cubic feet, size of rectangular box
   d. Cubic feet that would fit in space
   e. Pounds
   f. Miles
   g. Pounds
   h. Miles per hour
   i. Number of large seats and number of small seats
   j. Comfort rating from testing; volume per passenger

5. Combine items in (3) above

   a. Mileage and distance between refueling
   b. Total hauling weight = cargo capacity plus passenger weight.
   c. Volume remaining after passengers loaded (total volume - seat and passenger volume)

TABLE 9. (Contd.)

6. Reduce MOE list

   a. Delete mileage; it is cost item rather than capability item.
   b. Delete number of adults and children; consider all passengers equally.
   c. Delete total hauling weight; it duplicates number of passengers and cargo weight.
   d. Delete total volume; it duplicates number of passengers and cargo volume .

7. Further reduce MOE list

   a. Delete comfort index. It is too difficult to handle in paper analysis only.

8. Remaining MOEs

   a. Number of passengers possible
   b. Cargo volume remaining after passengers loaded
   c. Cargo weight capacity
   e. Distance between refueling
   f. Speed up 5% grade

NOTE: The above measures address the questions in (2), as well as other factors.

TABLE 10. Example of Top-Level Process for
Air-to-Ground Target Acquisition System for Attack.
(According to Table 8.)

1. Objective: Acquire targets for attack

2. Questions: What sensors should be used in the system? Can we use stand-off weapons with the system? How will system employment affect survivability?

3. List of MOEs

   a. Range of target acquisition
   b. Targets acquired
   c. Probability of acquiring targets
   d. Search time required
   e. False alarms
   f. Times system is severely degraded by weather
   g. Type of targets against which system is effective

4. Quantification of (3) above

   a. Thousands of feet
   b. Percent of total available
   c. Cumulative percent versus range in thousands of feet
   d. Seconds under fixed geometric conditions (same altitude and range)
   e. Percent of total reports that are not real targets
   f. Percent hours per day; percent days per year; percent per month as function of month (NOTE: Geographic location must be specified)

   g. Moving targets; radar-reflective targets, hot (infrared) targets; large targets; camouflaged targets

5. Combine items in (3) above:

   a. (a), (b), and (c) are similar

6. Reduce MOE List:

   a. Delete (a) and (b); use (c)

7. Further reduce MOE List

   a. Delete search time required since it is implied in (c) as range to target closes.

TABLE 10. (Contd.)

8. Remaining MOEs:

   a. Cumulative probability of acquiring targets as a function of range
   b. Percent false alarms
   c. Percent weather degradation
   d. Applicable target types

NOTE: Acquisition range could relate to survivability and stand-off weapons; sensor types relate to target types. MOEs do not explicitely address all questions in this example.

MOE Clarification

If the mission objective has been described very specifically in great detail, the first definition of the MOE may be good enough; this is not usually the case, however. It is usually necessary to clarify the mission objective so that the MOE, in turn, can be made specific enough to quantify. This process can involve iteration, negotiation, and compromise among the managers, sponsors, and design team members. It may occur several times throughout the design phase.

The clarification is often a simplification of the "super" capabilities initially desired by most sponsors and design engineers. The three descriptors of a MOE (capability, operating conditions, and quantification concepts) can be specified or simplified more or less independently, although sometimes they are interrelated. Some examples of the stages of clarification are shown for four systems in Tables 11, 12, and 13.

Top-Level MOE Approval

After following the guidelines provided in Table 8, and clarifying the MOE, there should be three descriptors (capability, operating conditions, and quantification concept) for each MOE. There will be one or more MOE for each separate mission. These top-level MOEs should be approved by: (1) sponsor, (2) project or program manager, and (3) other design team members. Potential or current system users should also be asked if the MOEs mean anything to them in the operational world. Do the MOEs address the questions that people are asking? Will the MOEs provide the data needed to aid in decision making?

Another iteration may be necessary to obtain a consensus on all aspects of the MOEs.

TABLE 11. Examples of the Stages of Specifying (Usually Reducing) a System's Desired Performance.

System	Stage	Performance
1. Antitank weapon	1st	Destroy tanks
	2nd	Destroy mobility of tanks
	3rd	Degrade weapon accuracy (firepower) of tanks
2. Antiship missile	1st	Sink any ship
	2nd	Destroy defensive fire power on any ship
	3rd	Destroy radar on any ship
	4th	Destroy defensive fire-power on a particular (enemy) ship
3. Fly fishing outfit	1st	Catch all kinds of fish
	2nd	Catch only trout
	3rd	Catch trout on dry flies only
4. Pilot ejection/recovery system (aircraft subsystem)	1st	Save pilot completely unharmed
	2nd	Save pilot; temporary spinal disk compression permissible
	3rd	Save pilot; some temporary injury permissible

TABLE 12. Examples of Stages of Specifying Operating Conditions.

System	Stage	Operating Conditions
1. Antitank weapon	1st	Anywhere, anytime
	2nd	On or near roads; fair to good weather; night and daytime
	3rd	On or near roads; fair to good weather; daytime
2. Antiship missile	1st	Anytime, anywhere
	2nd	Latitudes $\pm$ 80°; all types of weather; day and night
	3rd	Latitudes $\pm$ 80°; fair to good weather; day and night
3. Fly fishing outfit	1st	All waters, daytime, all seasons
	2nd	Streams, rivers, and lakes, daytime, summer
	3rd	Streams and rivers, daytime, summer
4. Pilot ejection/ recovery outfit	1st	Whenever pilot is in the aircraft
	2nd	Anywhere; aircraft speed >50 knots; aircraft in upright position
	3rd	200 ft < altitude < 60,000 ft; speed > 50 knots

TABLE 13. Examples of Stages in the Development of MOE Quantification Concepts.

System	Stage	Quantification Concept
1. Antitank weapon	1st	Probability of destroying tanks on one mission. Number of tanks that can be destroyed by one system on one mission.
	2nd	Percent tanks destroyed by one system on one engagement.
	3rd	Percent tanks of a total of nine tanks moving along a road that can be "mobility-killed" on one pass through the area by one system.
2. Antiship missile	1st	Probability of sinking a ship, given missile launch.
	2nd	Probability of hitting a ship, given missile launch.
	3rd	Probability of hitting an enemy ship, given a missile launch.
	4th	Probability of destroying the defensive firepower on a particular enemy ship, given missile launch.
3. Fly fishing outfit	1st	Number of fish caught in a day
	2nd	Number of trout hooked on a dry fly in one day.
	3rd	Number of trout hooked on a dry fly along a given stretch of river between 0900 and 1200 on a sunny day.
4. Pilot ejection/ recovery system	1st	Probability of safely eject ing/recovering a pilot when called upon to do so.
	2nd	Probability that ejection is within specifications; e.g., acceleration, duration, motion envelopes, etc.
	3rd	Probability that all subsystems function within specifications.

SECOND-LEVEL MOEs

The general functions (Figure 7, Tables 3 and 4) have only been used thus far to determine when to stop separating missions. They can now be used to generate the second-level MOEs.

It is important to note that the general functions have not yet been allocated to any particular subsystem, component, or human operator. However, MOEs usually can still be developed for each.

General Function Quantification

The general functions can be described in terms of the system, mission, and employment concept. The descriptions should provide enough detail for use in listing ways that performance of the functions might be quantified. The processes given in Table 3 can be used to develop alternative quantification methods similar to those shown in Table 13. Table 14 gives an example taken from the antitank weapon system mentioned earlier. Table 15 is included to illustrate that the same techniques can be used on vastly different systems (tank attack and fly fishing). Besides, it's fun to think about.

Table 14 lists more than one quantification concept for any one function; the same could have been done for Table 15. It is necessary to select one concept from the alternates for use in calculating the top-level MOE. The concept that is selected should be:

1. Required to calculate the top-level MOE that has already been selected
2. Related to the questions to be answered in the analysis
3. Based on system characteristics and employment concepts

TABLE 14. Brief Example of General Function Listing and Performance Quantification Concepts.

System: Antitank Weapon

General Functions:

a. Arrive in target area
b. Search for target
c. Acquire target
d. Fly to target
e. Damage target

Performance Quantification Concepts (Second level MOEs):

a. Accuracy in arriving at predesignated point; heading accuracy when entering target area; time accuracy compared to required "time-on-target".
b. Time spent in target area before target is found; number of passes through target area before target is found; range at which target is found.
c. Percent targets found; number of engagements when non-target is identified as a target; cumulataive percent targets found as a function of range from the target.
d. Miss distance (in two or three dimensions).
e. Probability of: Completely destroying the target and crew; destroying the mobility of the target; damaging the target so it cannot perform as required in combat.

TABLE 15. Another Brief Example of General Function Listing and Performance Quantification Concepts.

System: Fly-Fishing Outfit

General Functions:

a. Identify likely location of trout in stream and/or
b. Locate any trout rising to feed on the surface
c. Select dry fly and tie onto flyline
d. Move (includes wading) into casting position
e. Cast fly to correct location
f. Hook trout when/if strike occurs
g. Play trout to where it can be netted
h. Net trout

Performance Quantification Concepts (Second level MOEs):

a. Percent "likely locations" correctly identified along given stretch of a stream/river.
b. Percent of rising trout correctly spotted.
c. Probability of selecting "reasonable" fly for the occasion; percent of flies correctly tied onto line.
d. Percent of the time good casting position can be taken without scaring trout; percent of the time position can be taken without falling or getting wet (wader evaluation).
e. Percent of the time fly is cast to the proper location and lands without scaring fish.
f. Percent of the strikes during which the trout is also hooked.

g & h. Percent of the time the trout is played and brought in until it can be netted.

Combining Second-Level MOEs

As has been implied above, a second-level MOE is defined as a measure of how well a general function is performed. When the general functions are all performed as planned, the mission has also been performed, or completed.

The top-level MOE is calculated from the second-level MOEs, with care taken to correctly combine appropriate metrics. This is the point that mathematics enters the MOE development process, and to some extent, the development of the effectiveness algorithm (Figure 1) has begun.

The way that the second-level MOEs are combined is a function of their particular characteristics, and the particular problem at hand. Developing several methods, or listing many examples from "case studies" are beyond the scope of this paper; one example will be given, however.

Probability/Percent. One MOE is the probability of completing a mission, and/or percent missions successfully completed. In other words, the expectation one might have of success, and the fraction of the time that things will proceed as desired.

Table 14 gives brief examples of the general functions listing and the concepts of performance quantification. The following paragraphs give a better understanding of:

1. The measures in Table 14 could be stated as:

a. Probability of arriving in the target area within ± 1 mile in range and ± 5 degrees in heading from that planned.

b. Probability of getting the targets within view of the system sensors.

c. Probability of detecting and recognizing the target in time to turn toward it.

d. Probability of coming within 10 feet of the target.

e. Probability of damaging the target to the desired level (see top level MOE).

The top-level MOE could then be expressed as:

$$P_{success} = P_a \times P_b \times P_c \times P_d \times P_e \quad (1)$$

The probabilities are conditional; that is, the system could not get within 10 feet of the target unless it had arrived in the target area.

The probabilities can be simply combined as shown above if they are independent, a condition that must be established. If they are not independent, a different formulation would have to be developed. Redundant (or parallel) data processing and actions would also lead to a different formulation than the "series" situation represented in Equation (1).

It can be seen that the probabilities listed in the example are getting specific enough so that the employment concepts and system characteristics are pertinent in their formulation. The next step in the process is to figure out how to calculate each of the probabilities.

THIRD-LEVEL MOEs

In the procedure that has been developed thus far in this report, some, or most third-level MOEs could be considered to be measures of performance, as indicated in Figure 3.

It is not worth quibbling about whether to call these quantities measures of effectiveness or measures of performance. It helps, of course, if any given technical report defines its terms and is consistent in their use. Suffice it to say that one often finds a transition in terminology between measures of effectiveness of a mission, and measures of performance of a single task performed in the conduct of the mission, sometimes with undefined terms separating the two extremes.

Human Operator Performance

The capability of the human operator to perform tasks in system operation enters the analysis at about the third level in the MOE hierarchy (Figure 3). In many cases, human performance is a direct input to calculating one or more of the probabilities shown in Equation (1).

Probability-type MOEs, like those in the example, require probability-type input data; the form of operator performance data discussed in Reference 1 stresses this point. Operator performance data to be used in analysis must be in a particular form (as determined by the analysis). For example, mean scores will not be useful if score distributions are required. It follows that the people generating human performance data must either have exact data requirements (or specifications), or themselves be familiar with the nature of analysis.

Functions and Tasks

The functions illustrated in Figure 7 must be made more specific to develop the third-level MOEs. In some cases, several tasks must be performed to accomplish a function; the function MOE would then be made up of several measures of task performance, combined in a physically and mathematically appropriate way.

One example from Tables 11, 13, and 14 is summarized in Table 16. The second-level MOEs are expanded into functions, as mentioned previously, in Table 17.

TABLE 16. Example of Top- and Second-Level MOEs for Antitank System.

MOEs	Quantification
Top-level	
Ability to destroy mobility of tanks	Percent tanks of a total of nine tanks moving along a road that can be "mobility-killed" on one pass through the area by one system.
Second-level	
1. Ability to acquire target	Cumulative percent targets found as a function of range from the target.
2. Ability to fly toward target	Cumulative percent of aircraft that find target in time to fly to correct weapon release point.
3. Ability to damage target	Miss distance (in two or three dimensions) of the weapon. Probability of destroying the mobility of the target.

TABLE 17. Expansion of Second-Level MOEs Shown in Table 16.

Second-level MOEs	Functions	Measure of performance
1. Ability to acquire target	a. Scan terrain ahead of aircraft	Probability that target is brought within field-of-view (FOV).
	b. Detect target	Probability that target is detected given that it is in FOV.
	c. Identify target	Probability that target is identified as something to be attacked, given that it is detected.

TABLE 17. (Contd.)

Second-level MOEs	Functions	Measure of performance
2. Ability to fly toward target	a. Turn aircraft	Roll-in time "G"s in turn
	b. Roll out of turn	Time Accuracy in final heading
	c. Fly toward target	Tracking accuracy Tracking time required Probability of flying to correct weapon release points.
3. Ability to damage target	a. Weapon flies to target	Miss distance
	b. Warhead detonates	Probability of detonating
	c. Explosion/fragmentation damages target	Level of damage given miss distance

At this level in the analysis, a function allocation will have been done, where the functions are "assigned" to system components or human operators. Performance requirements for both humans and components can be established. At this point in the analysis, the analyst has really moved out of Box 3 in Figure 1 (specify MOEs) and into Boxes 4 and 6.

Although the major MOE development has been accomplished, it will still be going on at the more detailed levels of analysis, with the inevitable requirement to modify MOEs as more is learned about the system and scope of the analysis.

SUMMARY

This report illustrates that the MOEs associated with any particular system or analysis are hierarchical in nature. The top-level hierarchy included factors such as cost, survivability, reliability, and capability. The second-level hierarchy was used to illustrate an expansion of capability MOEs, which were the topic of this paper.

In the capability hierarchy, there is a transition between mission MOEs and individual task performance. It is possible to go down at least two levels in the hierarchy before encountering individual system components or human operators of components. There need not be a "visible" connection between mission capability and individual human operator performance, unless special attention is given to making the connection explicit.

IMPLICATIONS FOR HUMAN FACTORS

Implications that can be taken from the material presented in this report are given in the following three categories.

Human Factors Analyst

An analyst working at any level in the MOE hierarchy must be familiar with the MOEs at the levels both above and below his or her own. The analyst must understand the lower level MOEs (or performance data) so as to not misuse them, and the product of the analysis must be useful at the level above. The analyst must be able to limit the scope of the work so that something can be accomplished, yet have a broad enough overview so that the correct inputs are used from below, and the "right" questions are answered by the analysis results.

Human Factors Experimenter

The Human Factors experimenter conducting simulations or tests within a project structure must understand what kind of data is required, and the form of the data that is usable in the analysis. The experimenter must either be given specific data requirements, or know enough to develop the requirements by examining the type of analysis and MOEs being used.

The experimenter collecting so-called "baseline" data has a more difficult task. Generic experiments have no system development structure from which requirements can be derived. There are no MOEs that

require input data. It is often the case that such data are not useful when analysis requirements finally come along.

One could argue that such generic experiments are useful only in the human factors education context (i.e., to allow the student to demonstrate the ability to design and conduct experiments).

Such experimental results might be made more useful if a system development program is hypothesized and MOEs are developed as a first step in defining the experiment. The inclusion of this step in the design of generic, or "baseline data" experiments is worth trying in order to increase the usefulness of the results.

Human Factors Manager

This report has provided some insight, or another view, of why a "disconnect" between operator performance (or human factors) and system effectiveness is often perceived. The problem in establishing the worth of human factors in the system design process lies partly in the fact that operator performance is found at the lower levels in the MOE hierarchy. The program manager, sponsor, or person with the money tends to be concerned about the higher level MOEs. Operator performance is not often seen explicitly at these levels.

Operator performance, per se, must be carried upward in the analysis procedure to demonstrate the payoff in adequately funding the human factors part of a development effort. The hypothetical MOEs for baseline work referred to above would also show human factors worth. The human factors analyst or engineer may be the only one motivated and qualified to conduct such analysis.

MOE DEVELOPMENT PROCEDURES

As mentioned earlier in the report, the guidelines for developing MOEs are collected together here in the summary for easy reference and use. The practitioner can follow the guidelines and go back to the text when clarification is required.

It is common to have more than one mission objective, and it is important to address them separately in the analysis. Figures 8 and 9 show how to separate the objectives. Figure 10 and Table 18 show the procedures to follow in developing capability top-level MOEs. Figures 11 and 12 can be used to generate lower level MOEs.

At this point in the analysis procedures, the analyst has moved beyond Box 3 in Figure 1, and has completed the subject of this report.

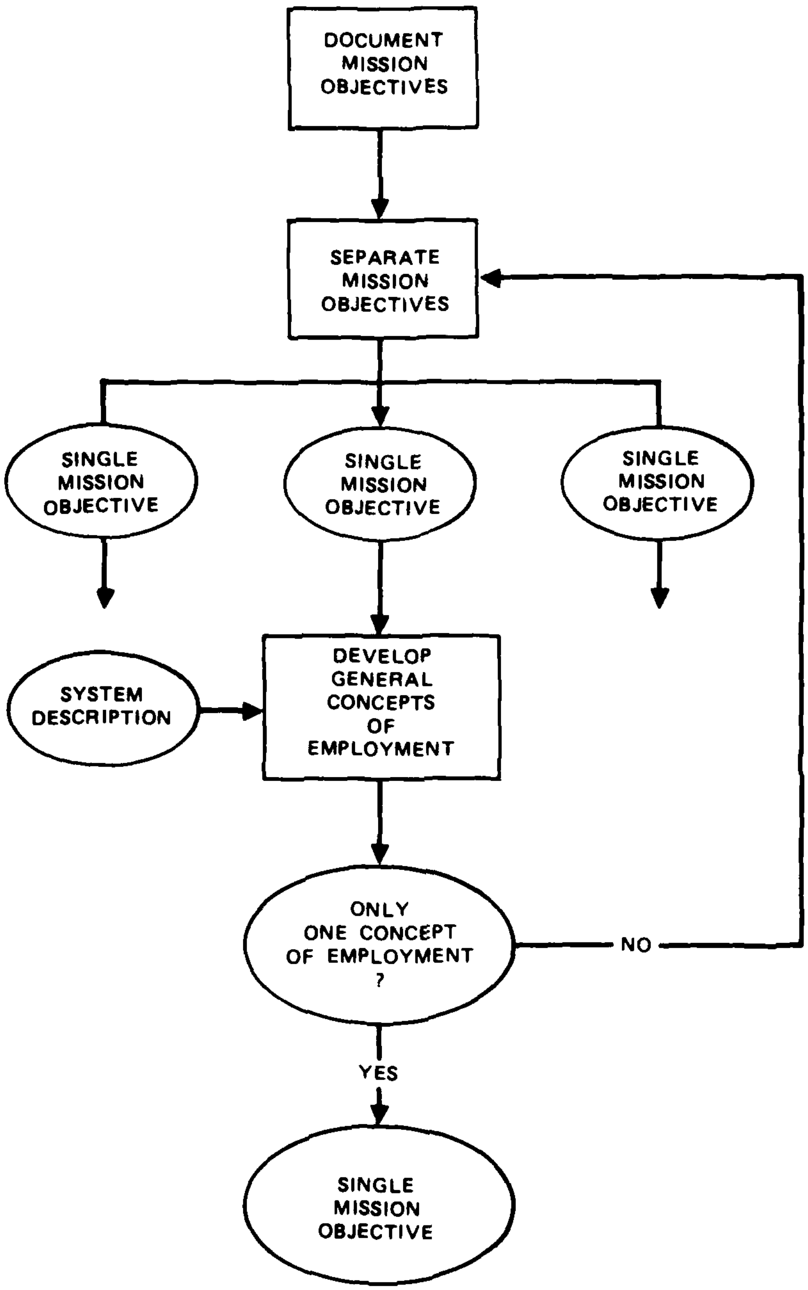


FIGURE 8. First Step in Separating Mission Objectives.

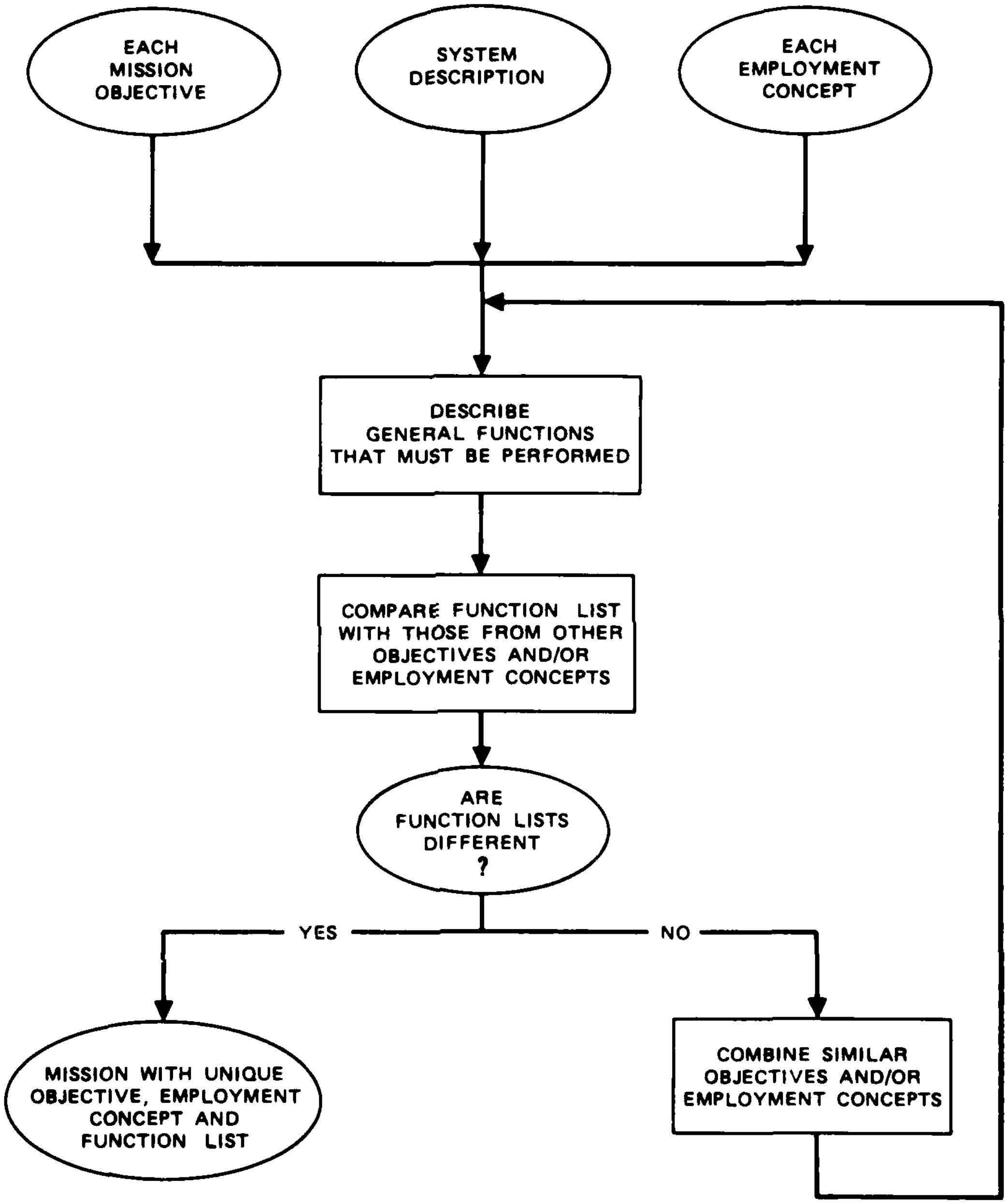


FIGURE 9. Second Step in Separating Mission Objectives.

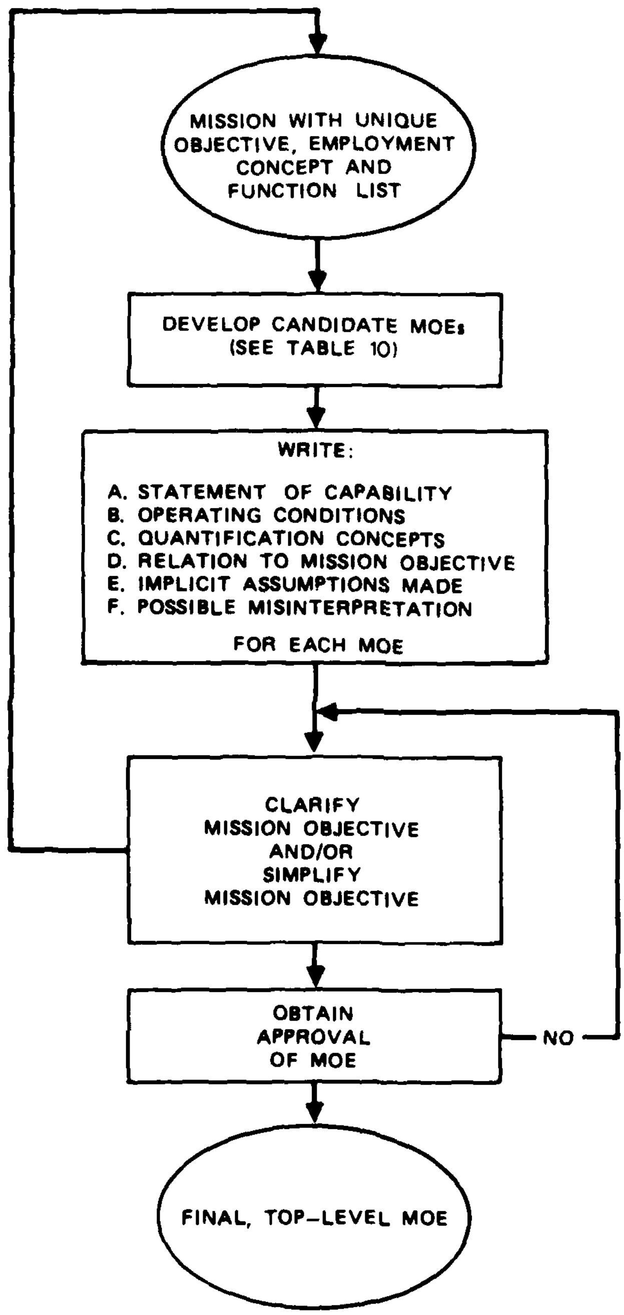


FIGURE 10. Development of Top-Level MOEs.

TABLE 18. Steps to Follow in Thinking up Candidates for Top-Level Measures of Effectiveness.

1. List the single mission objective as determined in the procedure illustrated in Figure 10.

2. List questions that need answering as obtained from sponsors, program managers, design engineers, etc.

3. Develop a list of many conceivable MOEs for the mission objective, without any initial constraints. Use a brainstorming technique if possible.

4. Write a description of the Quantification Concepts for each MOE listed.

5. Categorize the MOEs into groups of similar measures.

6. Reduce the list by combining (or discarding) duplicate or redundant MOEs.

7. Further eliminate MOEs from the list beacause of:

   a. Technical infeasibility
   b. Economnic infeasibility
   c. Weak or no relation to mission objective

8. List the remaining Top-Level MOEs for the Single Mission Objective given in (1) above.

9. Repeat the process for each Single Mission Objective.

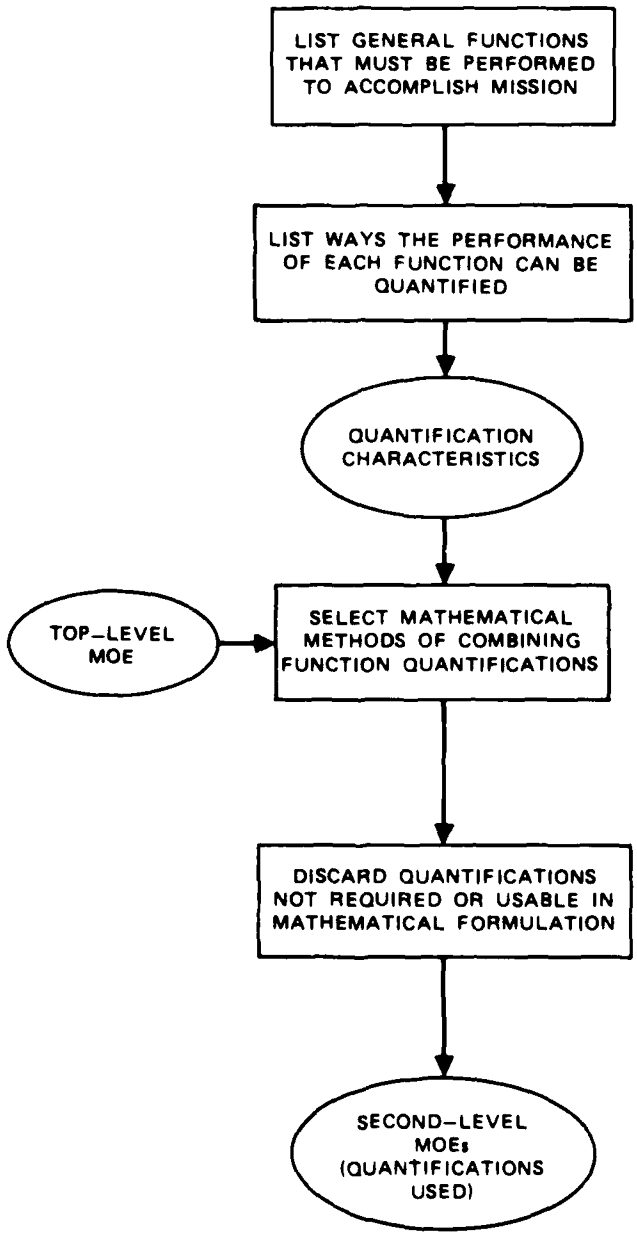


FIGURE 11. Development of Second-Level MOEs.

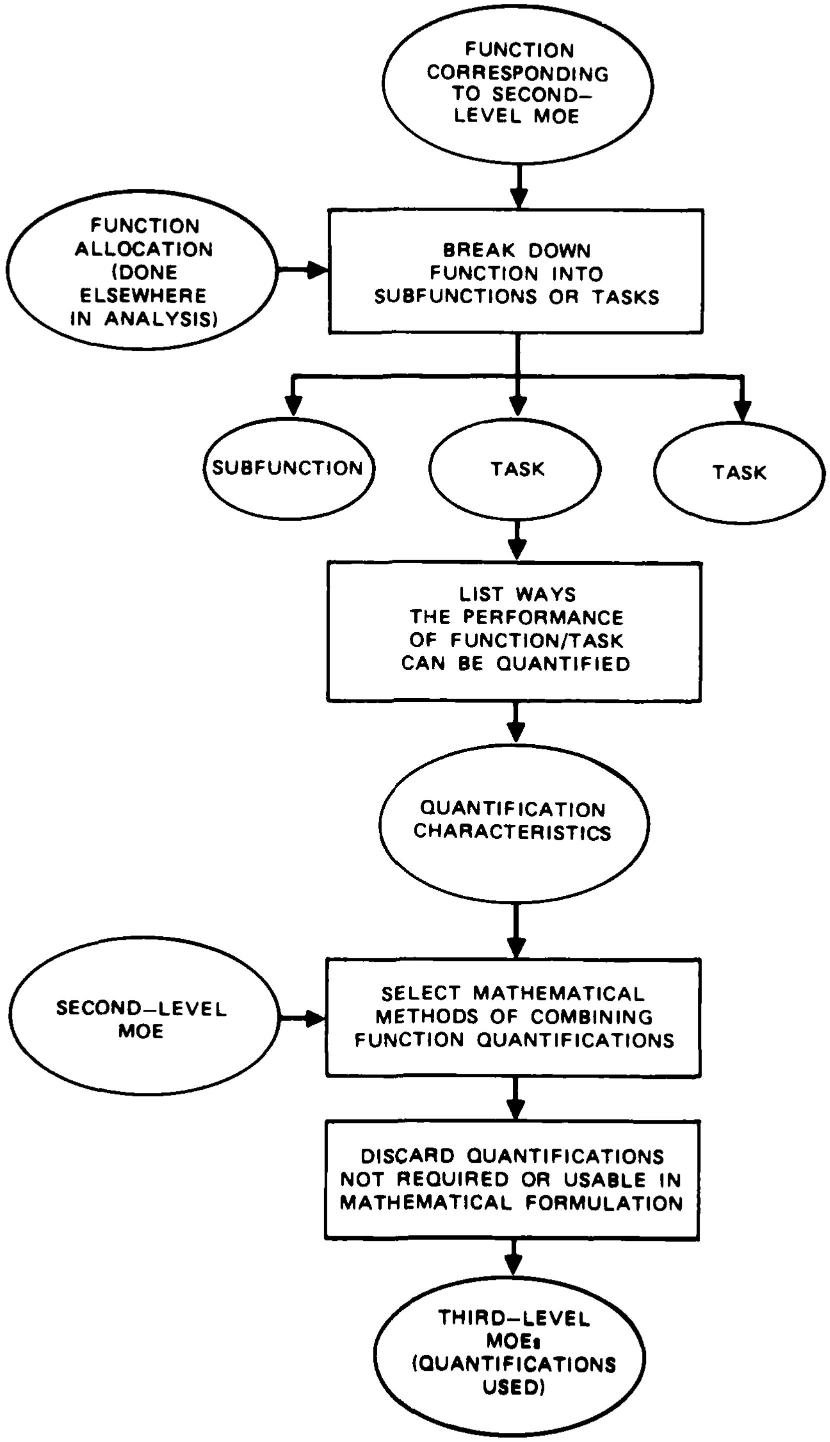


FIGURE 12. Development of Third-Level MOEs.

Appendix

PUBLISHED MOEs AND PERFORMANCE MEASURES

In addition to the general guidelines cited and provided in this report, some of the documents reviewed give examples of specific MOEs and performance measures (Table A-1). The procedures recommended in this report should still be followed to ensure continuity within the MOE hierarchy. But information given in Table A-1 can be used in the brainstorming process referred to in Table 18.

TABLE A-1. Examples of Specific MOEs.

Subject	Reference
Army weapons and tactics	3, 11, 13
Camouflage	14
Navy carrier landings	7, 8
Naval operations (Top-Level)	15
Air-to-air combat	9, 16
Airborne forward air controller	10
Air-to-surface attack	12, 16
Shipboard nuclear security	17
Pilot performance	18, 19
Air reconnaissance	16

MOE DEFINITIONS

In the Navy, availability is equivalent to readiness and dependability is equivalent to reliability.

Another definition is found in a Navy document (Reference 20):

> Systems performance effectiveness can be defined as, "a measure of the extent to which a system can be expected to complete its assigned mission within an established time frame under stated environmental conditions".

An Army document (Reference 13) gives the same definition as has been found in Air Force sources (Reference 2). Reference 13 gives a more specific definition of the three components of systems effectiveness:

1. Availability is a measure of the degree to which an item (or is the chance that a system) is in the operable or committable state at the start of a mission when the mission is called for at an unknown (random) point in time.

2. Dependability is a measure of the system operating condition during the performance of the mission, given the condition of the system at the start of the mission (availability). Reliability, survivability, and maintainability are included in the dependability concepts.

3. Capability is a measure of or the chance that a system will achieve mission objectives given the conditions during the mission (dependability).

The concept of breaking down system effectiveness into three components was evidently originated in an early Air Force contracted study (Reference 21), and has been found useful ever since.

A definition of a MOE is a starting point in its description. The quantitative measure used to compare the effectiveness of alternative courses of action in achieving the objective is called the Measure of Effectiveness (Reference 22).

A criterion is a measure or standard by which performance of a system is evaluated (Reference 23).

A measure of effectiveness is a quantitative expression of the degree to which a system fulfills its objectivea (Reference 24).

MOE definitions found in documents in the Armed Forces get a little more complicated:

> A FOM is a measure of system effectiveness pertinent to one or more mission requirements (Reference 2).

Reference 2 breaks the concept into three parts: availability, dependability, and capability. To expand upon the above definition:

> A capability FOM is a measure of the ability of a system to achieve mission objectives, given specific system conditions during the mission. It specifically accounts for the performance spectrum of a system (Reference 2).

Reference 20 uses several terms: figure of merit, system effectiveness figures, system performance effectiveness measures, effectiveness measures, and effectiveness criteria. This measure is divided into two distinct but related factors:

P_C - the performance variable, or capability and its associated range of values.

P_T - the detailed time-dependency of performance, which allows reliability, maintainability, availability, etc., to be treated as modifiers of performance.

MOE HIERARCHY

Table A-1 (page 47) shows what could be called a hierarchy of analysis; each level may have different analysis techniques and different MOEs. The concept of hierarchies will be expanded here to help produce the guidelines for developing MOEs.

Tables A-2 through A-5 show listings similar to that shown in Table A-1. Although the references from which these tables were taken were written for different purposes, the common concept is that there are measures of effectiveness (or performance) at each of these levels. They are combined in some way to get the measure at the next higher level.

TABLE A-2. Figure-of-Merit Hierarchy (Reference 2).

FOM level	Example
Top-level	Force structure composed of different system classes.
First-level	Single system with "dependent" system (e.g., aircraft equipped with missile.)
Second-level	Single system
Third-level	Subsystem or human operator

TABLE A-3. Mission Hierarchy. (Reference 16)

Mixed system force missions
Multiple system missions
Single system missions

TABLE A-4. Assessment Hierarchy. (Reference 14)

Force level
Tactical operations
System operations
Design

TABLE A-5. The Hierarchy of Measures of Effectiveness (Reference 11).

National security (Political level)
Major mission (OSD-Joint Chiefs of Staff level)
Program element (Department of the Army level)
Military worth/combat effectiveness
System performance capability level
System characteristics level
Component characteristics level

MOE CHARACTERISTICS

It may be helpful to cite some of the properties of MOEs that analysts have found necessary, useful, and/or desirable.

Multiplicity

The difficulty of finding a single criterion by which to judge a system has been a common experience (References 3, 14, 25, and 26). When a system is tasked to perform several independent functions (e.g., navigation and weapon delivery), it is often advisable to carry the separate MOEs along as far as possible up the hierarchy. A requirement on the system to perform different assignments of missions (e.g., target attack and search and rescue) also leads to using separate MOEs.

Some criteria used in equipment design cannot easily be quantitatively related to system performance, yet they "make good sense". The comfort, long term health (e.g., avoid hearing impairment), and actual performance by the human operator on a mission all have separate MOEs that should affect design decisions.

Multiple MOEs must be combined into one MOE in some fashion for use in each design decision that is made. But for most levels of technical analysis, multiple MOEs are the rule rather than the exception.

Simplicity

To offset the notion of several MOEs, Attaway advises that a good general guideline in selecting a MOE is "to choose the narrowest goal possible in order to minimize analytic effort" (Reference 26). The simplification of MOEs during the analytic process, in order to end up with something manageable, is also a common experience (References 1 and 27).

Quantifiable/Measurable

Although design and other types of decisions are made in the course of a program based on information that is qualitative, an oft-cited, required characteristic of MOEs is that they be quantitative (References 11, 20, 22, and 28) or probabilistic (Reference 28). The concept of describing capability in terms of probabilities, percents, or ratios of numbers could be included under the quantitative descriptor.

Some documents (References 13, 22, and 29) have also included the requirement that a MOE be measurable. If one interpreted that requirement as meaning measurable in theory, or in concept, most MOEs that have been used would qualify. Lower level MOEs, such as component or human operator performance (Figure 3) can and are measured routinely. MOEs used in test and evaluation must be, and are measured. However, it is seldom practical to instrument and measure higher level MOEs such as the outcome of a battle. Many MOEs used in effectiveness analysis are never measured and, indeed, it would be impractical to do so (Reference 1).

Mission Related

The measure of effectiveness evaluates or predicts aspects of system performance relevant to operational issues. It therefore should be operationally credible (Reference 28) or in operationally-oriented form that can readily understood and used in planning (Reference 21).

Meaningful/Useful

As Quade wrote some time ago, "working out a systems analysis with a bad criterion is equivalent to answering the wrong question" (Reference 25). Others discussing the characteristics of MOEs have expressed the same requirement.

MOEs should be:

1. Oriented to issues, to the right decision level and the decision-maker (Reference 30)

2. Relevant (Reference 13)

3. Meaningful to the system designer, system analyst, user, mission analyst (Reference 20)

4. Specifically related to the design item characteristics (Reference 14)

The above statements illustrate the many uses of effectiveness analysis and the importance in choosing proper MOEs. MOEs should be multiple, simple, quantitative, mission-related, system-related, and meaningful to a number of people.

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